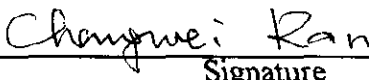



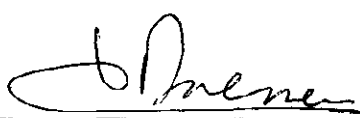
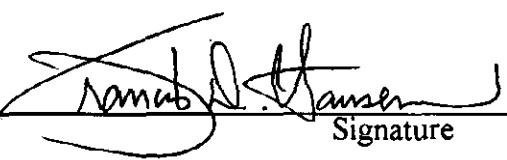


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**TITLE: PROCEDURES FOR DETERMINING THE GAS PERMEABILITY OF
THE COMPACTED BENTONITE**

Revision 0

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PROCEDURES FOR DETERMINING THE GAS PERMEABILITY OF THE COMPACTED BENTONITE

1. OBJECTIVES AND OUTLINE OF PROCEDURE

The objective of this test is to determine the gas permeability of compacted bentonite. The test is conducted on a cylindrical sample of compacted bentonite installed in a permeameter. The test is conducted by gas pressurization of the cylindrical sample on both ends, and by monitoring the gas pressure decay and/or flow rate at the higher pressurized end of the sample. The procedure closely follows Stormont (1990, Chapter 3).

2. Quality Assurance

All testing activities will comply with the SNL WIPP quality assurance program, and will be documented in scientific notebooks and on test report form in the Appendix. Results of testing as documented in notebook shall be reviewed by the UNR PI or designee (Dated and initialed).

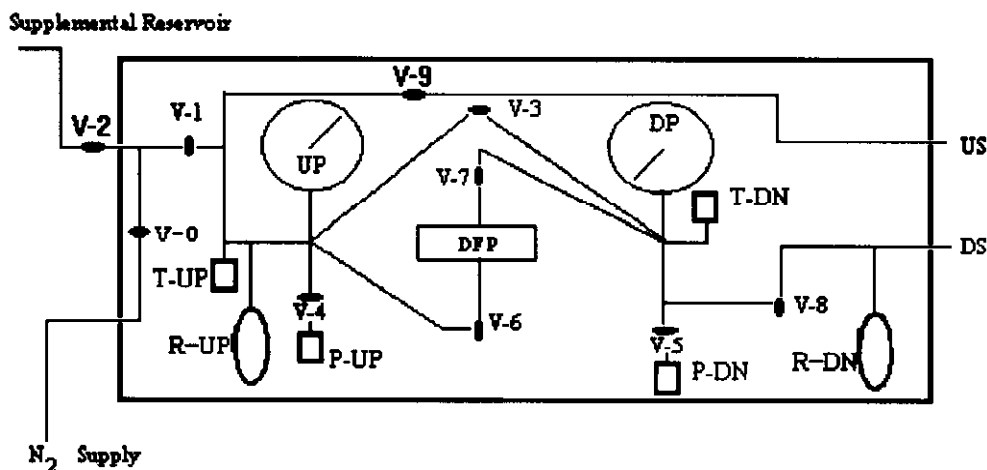
3. Records

All documentation of the testing activities and recording of the results should be identified as a QA record and submitted to the principal investigator.

4. APPARATUS

- 1) Permeameter
- 2) Pressure gages (2 for permeameter panel)
- 3) Pressure transducers (one for upstream, one for downstream and one for differential)
- 4) Thermometer
- 5) Thermocouples (one for upstream, one for downstream)
- 6) Nitrogen gas tanks
- 7) Steel disks
- 8) Porous stone disks
- 9) Data recording system (3497A Data Acquisition/Control Unit, Hewlett-Packard)

5. MATERIALS



Valves:

- V-0: Pressure transfer to supplemental reservoir
- V-1: Supplemental reservoir
- V-2: Pressure on switch for supplemental reservoir
- V-3: Communication
- V-4: Upstream transducer
- V-5: Downstream transducer
- V-6: Differential transducer
- V-7: Differential transducer
- V-8: Vent
- V-9: Pressure on Switch

Pressure gages:

- UP: For upstream pressure
- DP: For downstream pressure

Pressure Transducers:

- P-UP: Upstream
- P-DP: Downstream
- DFP: Differential

Thermocouples

- T-UP: Upstream
- T-DN: Downstream

Connectors:

- US: to top of permeameter
- DS: to bottom of permeameter

Reservoirs:

- R-UP: Upstream
- R-DN: Downstream

Figure 1 Control Panel for the Permeameter.

6. TEST PROCEDURE

6.0. Sample preparation

See WIPP Procedure 546.

6.1. Test Preparation

- 1) Assemble the split or the solid mold with the compacted bentonite cylinder, porous stone disks and endplates as a permeameter.
- 2) Connect the permeameter to the control panel.

6.2. Gas Flow Testing

6.2.1 Transient Flow Testing

- 1) Connect data acquisition system.
- 2) Connect nitrogen gas tank with regulating valve to the control panel (V-0 is open and V-2 is closed).
- 3) Valve V-3 is open, and valves V-6 and V-7 are open.
- 4) Valves V-4 and V-5 are open.
- 5) Valve V-9 is open and Valve V-8 is closed.
- 6) Apply equal gas pressure to both ends of the sample for 5 to 10 minutes.
- 7) Isolate upstream volume from downstream by closing the "communication" valve (V-3 is closed) and pressure switch V-9 is closed, and apply small pressure pulse (about 10% of the applied pressure) to the upstream reservoir and to the top of the sample. The pressure difference between the upstream and the downstream should be less than 15 psi (103.5 kPa).
- 8) Turn V-1 to close and turn pressure switch V-9 to open to start flow testing.
- 9) Record pressures which are applied to the top and bottom of the sample and pressure difference across the sample.
- 10) Record gas temperature in the upstream and downstream line.

Note: Upstream, downstream and differential pressures and temperatures are recorded with data acquisition system.

- 11) Repeat steps 6 through 10 at least twice.

6.2.2 Steady-State Flow Testing

- 1) Connect data acquisition system.
- 2) Connect nitrogen supplemental gas tank with regulating valve to the control panel (V-1 is closed and V-2 is open).
- 3) Turn V-0 to open, turn regulating valves of supplemental gas tank to full open.
- 4) Transfer gas pressure of about 30-40 psi from the gas tank to the supplemental gas tank (reservoir).
- 5) Turn V-0 to closed
- 6) Valves V-4 and V-5 are open.
- 7) Valves V-6 and V-7 are closed.
- 8) Valve V-8 is in the vent position.
- 9) Turn V-1 valve to open, and apply all pressure in the supplemental gas tank to the top of the sample.
- 10) Record upstream pressure and record the pressure decay in the upstream reservoir.
- 11) Record gas temperature in the upstream and downstream line.
- 12) Stop when the pressure in the supplemental gas tank is about 5 psi.
- 13) repeat steps 4 through 12 as needed.

6.3. Test Termination

- 1) Disconnect pressure supplier;
- 2) Release pressure in the test system by turning Valve V-8 to the vent position (Figure 1).
- 3) Disconnect the permeameter from the control panel;
- 4) Disassemble the permeameter;
- 5) Remove the compacted bentonite cylinder from the Proctor mold;
- 6) Observe and record or photograph physical nature of the compacted bentonite.

7. TEST RESULT ANALYSIS

7.1 Transient Flow Testing

Closely follows Stormont (1990), to determine overall permeability of the cylinder test assembly. The slope of the logarithm of the differential pressure change vs time is a straight line. The permeability of the sample is proportional to the slope :

$$k = \alpha (C_f \mu_f) \left[\frac{L}{A} \right] \frac{(V_d V_u)}{(V_d + V_u)} \quad (1)$$

(equation 3.6 in Stormont 1990)

where α is the slope, C_f is the average fluid compressibility, μ_f is the fluid viscosity, L is the sample length, A is the sample cross-sectional area, V_u and V_d are the upstream and downstream reservoir volumes, respectively.

α is give by (Brace et al., 1968):

$$\alpha = \frac{1}{t} \log \left[\frac{(P_u - P_{df})}{P_{df} \left(\frac{V_u}{V_d} + V_d \right)} \right] \quad (2)$$

where P_u is the upstream pressure, P_{df} is the downstream pressure at equilibrium after pressure decay of the upstream pressure, and P_{df} is the differential pressure between the upstream and the downstream at the beginning of the flow testing.

7.2 Steady-State Flow Testing

The permeability K under steady-state flow is defined by Darcy's equation:

$$\frac{Q}{A} = - \frac{K}{\mu} \frac{dP}{dL} \quad (3)$$

where Q is the volume flow rate (m^3/s), A is the cross-section area (m^2), dP/dL is the pressure gradient along the fluid flow path (Pa/m), μ is the viscosity of the fluid (centipoises), and K is the permeability (m^2).

Viscosity μ (centipoises) varies with temperature and is given by (Buzzard, 1991, p. 44):

$$\mu = a \left[\frac{T + 273}{10,000} \right]^c \quad (4)$$

where a and c are constant, and for nitrogen, $a = 0.224$ and $c = 0.720$ (Buzzard, 1991, p. 44). T is the temperature in $^{\circ}\text{C}$.

The volumetric flow rate Q can be determined from the pressure rate of change (eq. 3.7. in Stormont, 1990):

$$Q = \frac{dV_u}{dt} = \frac{V_u}{P_u} \frac{dP_u}{dt} \quad (5)$$

where V_u is the volume of the upstream reservoir (m^3), P_u is the upstream reservoir pressure (Pa), and t is time (s).

For ideal gas flow under isothermal, steady-state and one-dimensional conditions (Sullivan, 1988; Katz et al., 1959, p. 40), the permeability K is given by converting gas volumes at mean pressures to gas volumes at atmospheric pressure and by applying Eq. (3):

$$K = \frac{2\mu L}{A} \frac{P_a}{(P_u^2 - P_d^2)} Q \quad (6)$$

where P_d is downstream pressure and P_a is atmospheric pressure (Pa).

In the permeability test, the downstream pressure P_d equals the atmospheric pressure P_a . Then, by combining Eqs. (5) and (6), the permeability K is given by:

$$K = \frac{2\mu L}{A} \frac{V_u P_a}{P_u (P_u^2 - P_d^2)} \frac{dP_u}{dt} \quad (7)$$

7.3 Calculation

Run the PERMCAL program with the sample diameter, the sample length and the recorded test data (upstream pressure, temperature and time) to obtain the permeability of the compacted bentonite.

8. BACKING UP THE DATA

At the end of the each test put a floppy disk into the disk drive and copy the relevant test data from the hard disk. Repeat this for another backup copy. Record the name of the disk file and date in the lab notebook. Put the floppy disks in the QA file cabinets.

9. Calibration

All gages and pressure transducers on the control panel and the data acquisition system should have a valid calibration. The balance used to weigh samples and the compact compression machine should have a valid calibration. Standard weights should be used for accuracy checking (see WIPP Procedure 162) each time the balance is used. Record S/N's of scale, pressure gages, and transducers and standards, plus results of the checks in the scientific notebooks.

10. REFERENCES

- Brace, W.F., J.B. Walsh and W.T. Frangos, 1968, "Permeability of Granite under High Pressure," *Journal of Geophysical Research*, Vol. 93, No. 6, pp. 2225-2236.
- Katz, D.L., D. Cornell, J. A. Vary, R. Kobayashi, J.R. Elenbaas, F. H. Poettmann and C. F. Weinaug, 1959, *Handbook of Natural Gas Engineering*, McGRAW-HILL, New York, 802p.
- Stormont, J.C., 1990, "Gas Permeability Changes in Rock Salt During Deformation." Ph.D. dissertation, The University of Arizona, Tucson, Arizona, 387p.
- Sullivan, B. R., 1988, "Permeability Testing System for Grout, Concrete, and Rock," in *Permeability of Concrete*, Whiting and Walitt Editors, American Concrete Institute, Detroit, pp. 159-174.
- Buzzard, W.S., 1991, "Physical Properties of Fluids," in *Flow Measurement*, D.W. Spitzer editor, Instrument Society of America, Research Triangle Park, NC.

**Test Report Form:
 The Gas Permeability Test for the Compacted bentonite**

Test date(s) _____	Compaction test information:
Flow test number _____	Compaction method: _____
Data file name: _____	Water content (%) _____
Test conducted by: _____	Rammer weight (lb) _____
Test report reviewed by: _____	No. of blows/layer _____
Data acquisition system: _____	Compaction energy: _____

Sample Dimensions:

For measurement purpose, divide the end face of the sample into four equal sectors by drawing two mutually perpendicular diametric lines through the center. Name one as 0-180 and the other as 90-270.

1. Diameter

$D_{0-180} =$ _____ inch $D_{90-270} =$ _____ inch
 Average diameter : _____ (in) x 2.54 _____ (mm)

2. Height (unfilled with compacted bentonite)

$H_0 =$ _____ inch $H_{90} =$ _____ inch
 $H_{180} =$ _____ inch $H_{270} =$ _____ inch
 Average height $H_{av} =$ _____ (in) x 2.54 _____ (mm)

3. Sample height (H)

Mold height $H_m = (8.0) (5.0)$ inch Height of steel disks $H_{sd} = (1.125)$ inch
 Sample height $H = H_m - H_{sd} - H_{av} = (6.875) (3.875) - H_{av}$
 $=$ _____ (in) x 25.4 _____ (mm)

4. Area : _____ (in²) x 25.4 _____ (mm²)

5. Volume : _____ (in³) x 25.4 _____ (mm³)

6. Weight : _____ (lb) x 0.454 _____ (kg)

Observations: